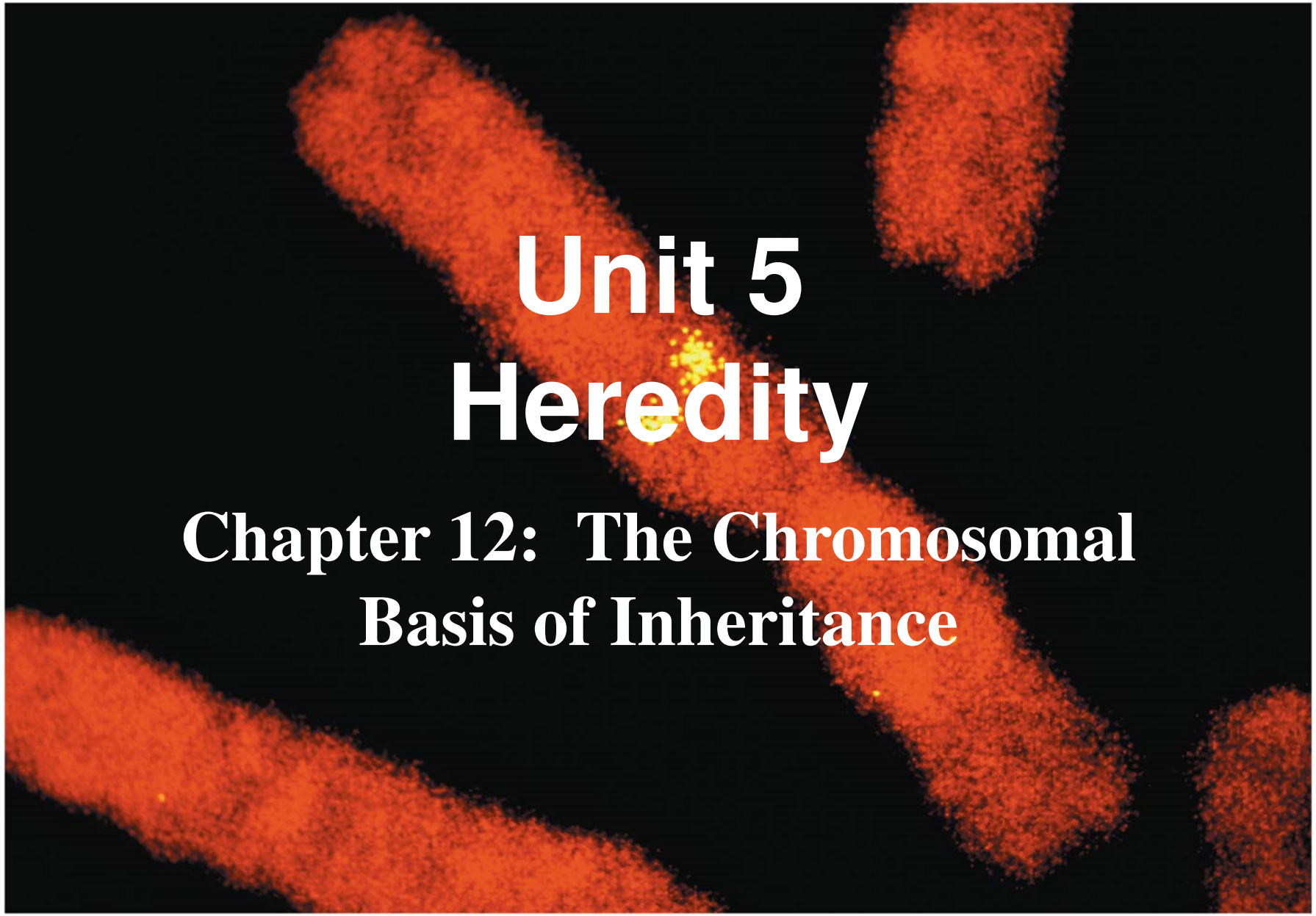


Unit 5
Heredity

Chapter 12: The Chromosomal Basis of Inheritance

Overview: Locating Genes Along Chromosomes

- Mendel's "hereditary factors" were genes
- Today we know that genes are located on chromosomes
- The location of a particular gene can be seen by tagging isolated chromosomes with a fluorescent dye that highlights the gene

Concept 12.1: Mendelian inheritance has its physical basis in the behavior of chromosomes

- The **chromosome theory of inheritance** states
  - Mendelian genes have specific loci (positions) on chromosomes
  - Chromosomes undergo segregation and independent assortment
- The behavior of chromosomes during meiosis can account for Mendel's laws of segregation and independent assortment

Figure 12.2

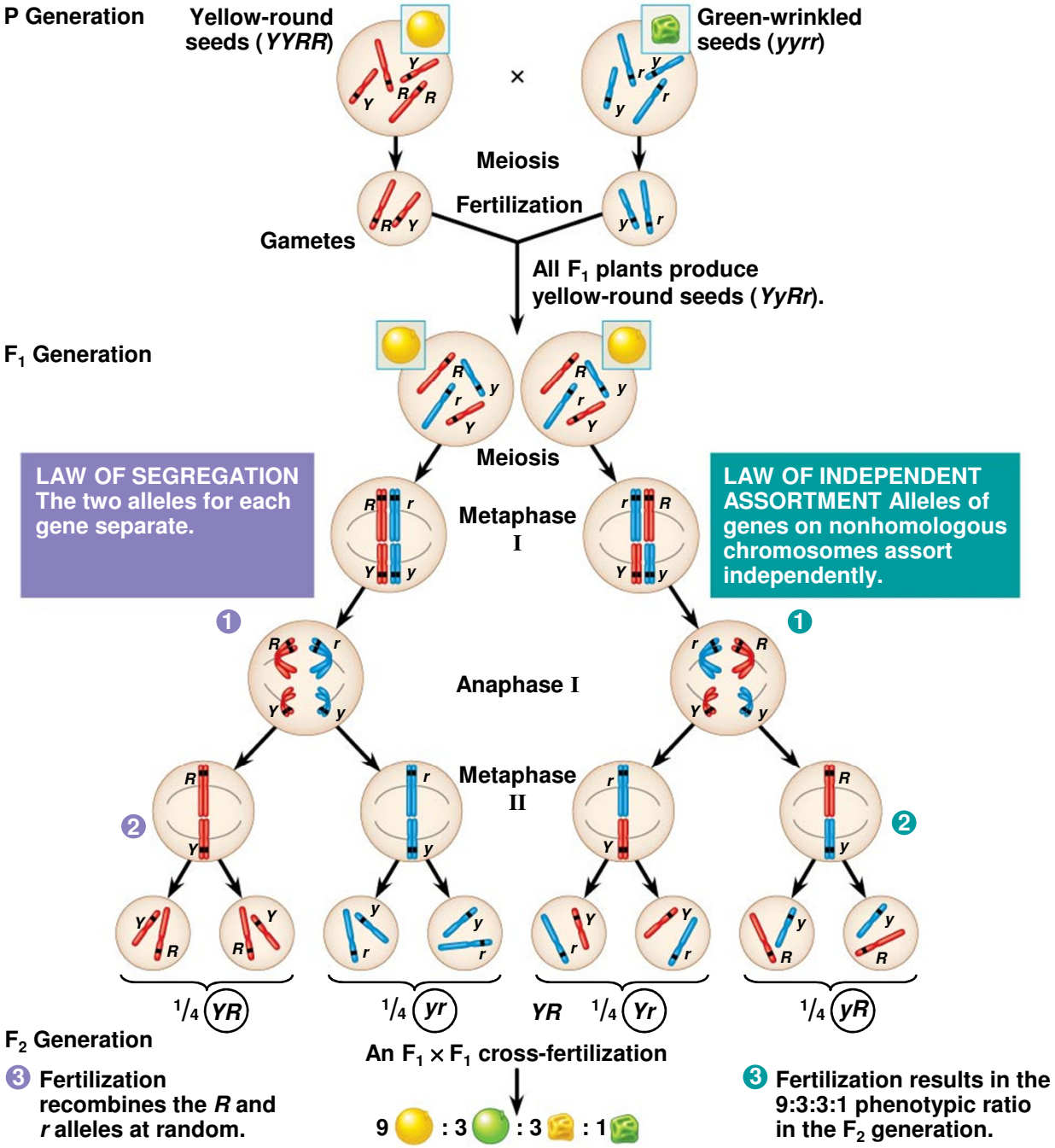

P Generation
Yellow-round seeds (YYRR)
Green-wrinkled seeds (yyrr)
Meiosis
Fertilization
Gametes
All F1 plants produce yellow-round seeds (YyRr).
F1 Generation
LAW OF SEGREGATION The two alleles for each gene separate.
LAW OF INDEPENDENT ASSORTMENT Alleles of genes on nonhomologous chromosomes assort independently.
Meiosis
Metaphase I
Anaphase I
Metaphase II
1/4 YR
1/4 yr
YR
1/4 Yr
1/4 yR
F2 Generation
An F1 × F1 cross-fertilization
9 : 3 : 3 : 1
3 Fertilization recombines the R and r alleles at random.
3 Fertilization results in the 9:3:3:1 phenotypic ratio in the F2 generation.

Figure 12.2a

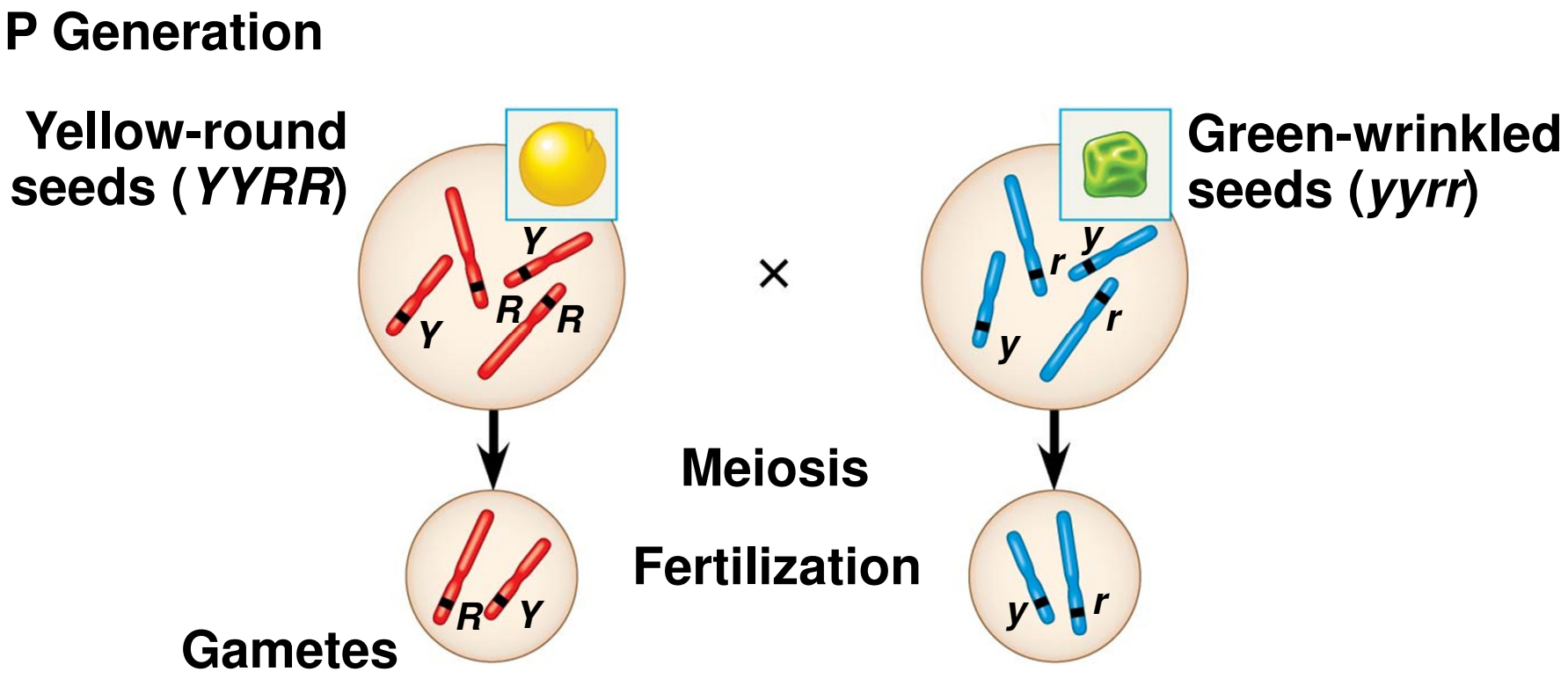

P Generation
Yellow-round seeds (*YYRR*)
Green-wrinkled seeds (*yyrr*)
Y
Y
R
R
×
y
r
y
r
Meiosis
Fertilization
R
Y
y
r
Gametes

Figure 12.2b

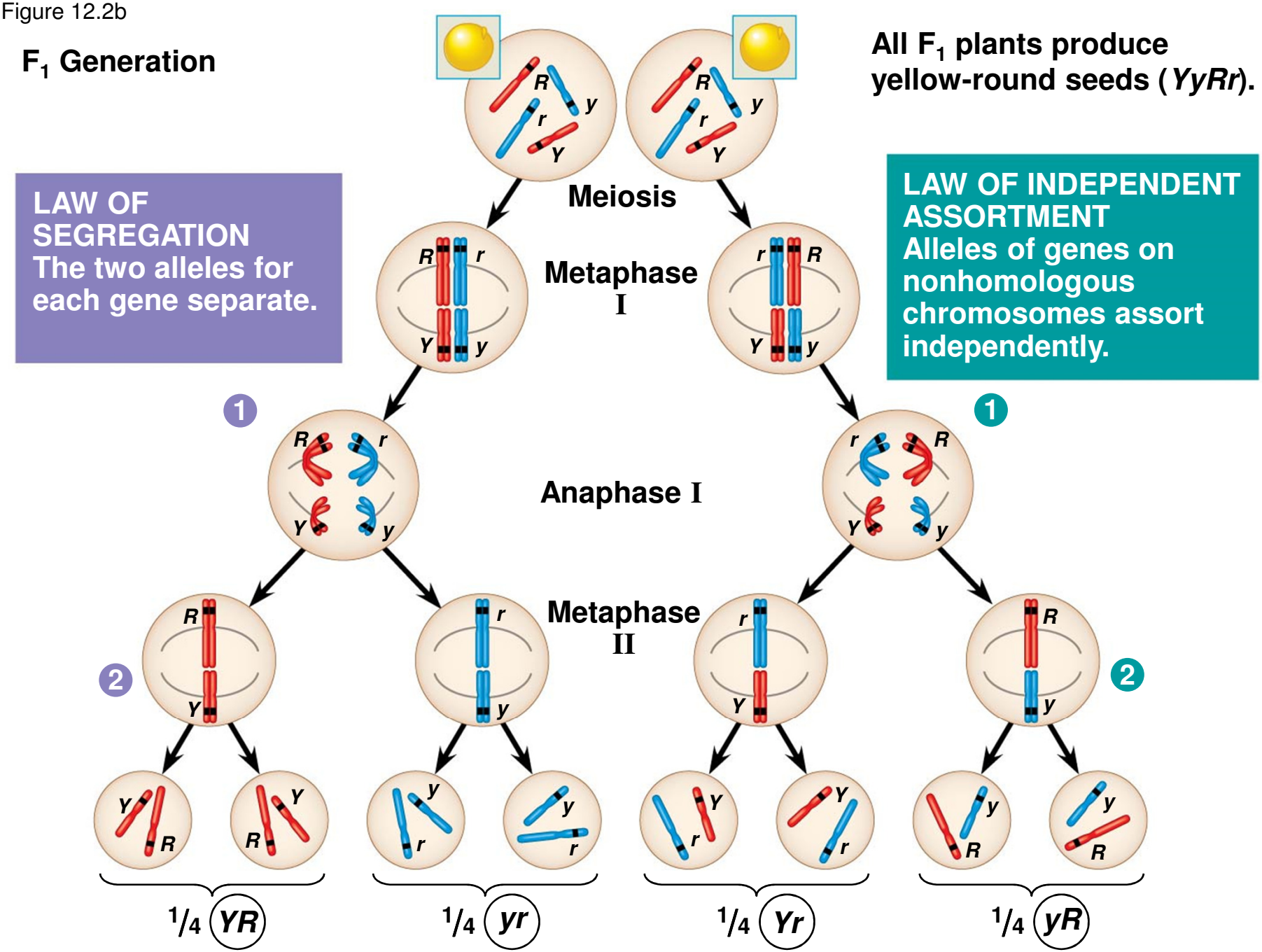

F1 Generation
All F1 plants produce yellow-round seeds (YyRr).
LAW OF SEGREGATION
The two alleles for each gene separate.
LAW OF INDEPENDENT ASSORTMENT
Alleles of genes on nonhomologous chromosomes assort independently.
Meiosis
Metaphase I
Anaphase I
Metaphase II
1
2
1/4 YR
1/4 yr
1/4 Yr
1/4 yR

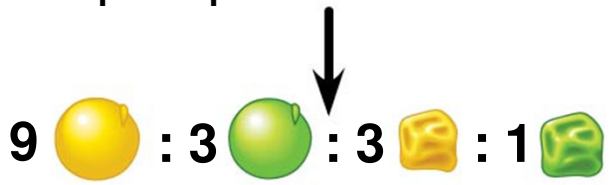
Figure 12.2c

LAW OF SEGREGATION

F_2 Generation

3 **Fertilization recombines the *R* and *r* alleles at random.**

An $F_1 \times F_1$ cross-fertilization



LAW OF INDEPENDENT ASSORTMENT

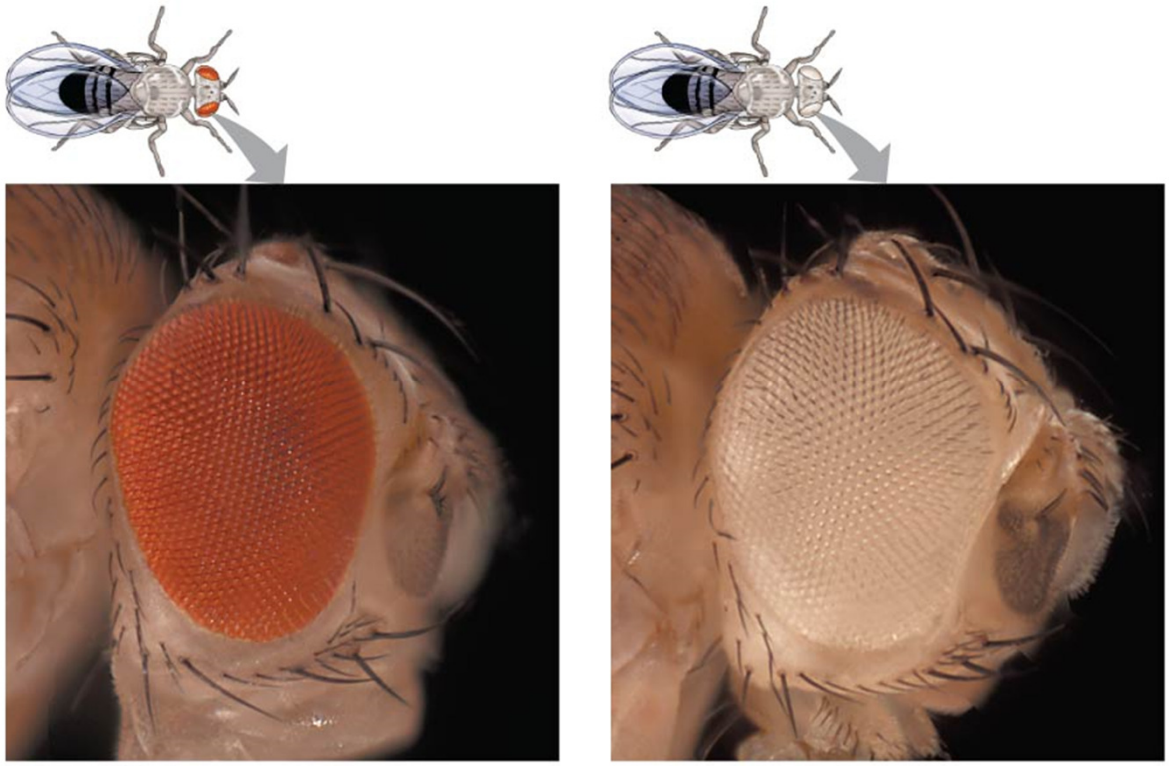
3 **Fertilization results in the 9:3:3:1 phenotypic ratio in the F_2 generation.**

Morgan's Experimental Evidence: *Scientific Inquiry*

- Thomas Hunt Morgan and his students began studying the genetics of the fruit fly, *Drosophila melanogaster*, in 1907
  - Experiments provided evidence that chromosomes are the location of Mendel's "heritable factors" (genes)
- Several characteristics make fruit flies a convenient organism for genetic studies
  - They produce many offspring
  - A generation can be bred every two weeks
  - They have only four pairs of chromosomes
    - 3 pairs of autosomes and 1 pair of sex chromosomes

- Morgan noted **wild-type**, or normal, phenotypes that were common in the fly populations
- Traits alternative to the wild type are called *mutant* phenotypes
- The first mutant phenotype they discovered was a fly with white eyes instead of the wild type, red

Figure 12.3



Correlating Behavior of a Gene's Alleles with Behavior of a Chromosome Pair

- In one experiment, Morgan mated male flies with white eyes (mutant) with female flies with red eyes (wild type)
  - The F_1 generation all had red eyes
  - The F_2 generation showed the classical 3:1 red:white ratio, but only males had white eyes
- Morgan concluded that the eye color was related to the sex of the fly

- Morgan determined that the white-eyed mutant allele must be located on the X chromosome
- Morgan's finding supported the chromosome theory of inheritance
  - A specific gene is carried on a specific chromosome
    - Eye color gene on the X chromosome

Figure 12.4a

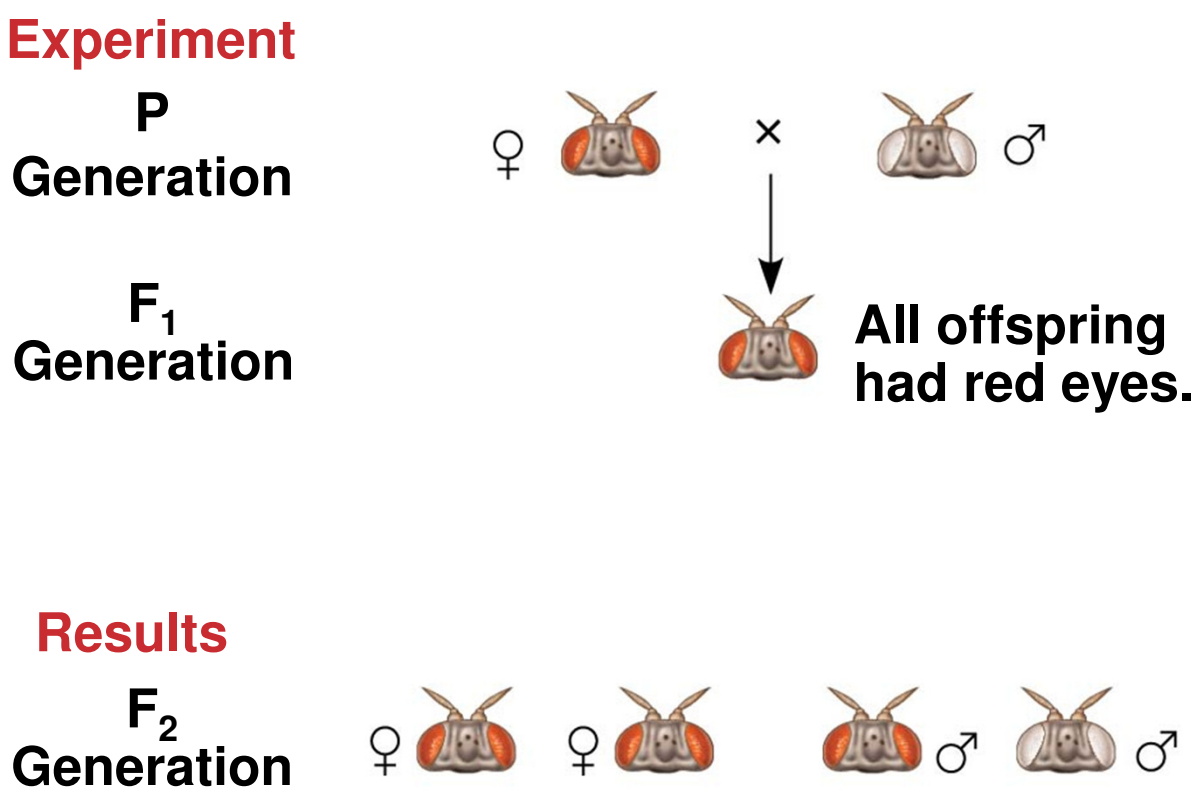
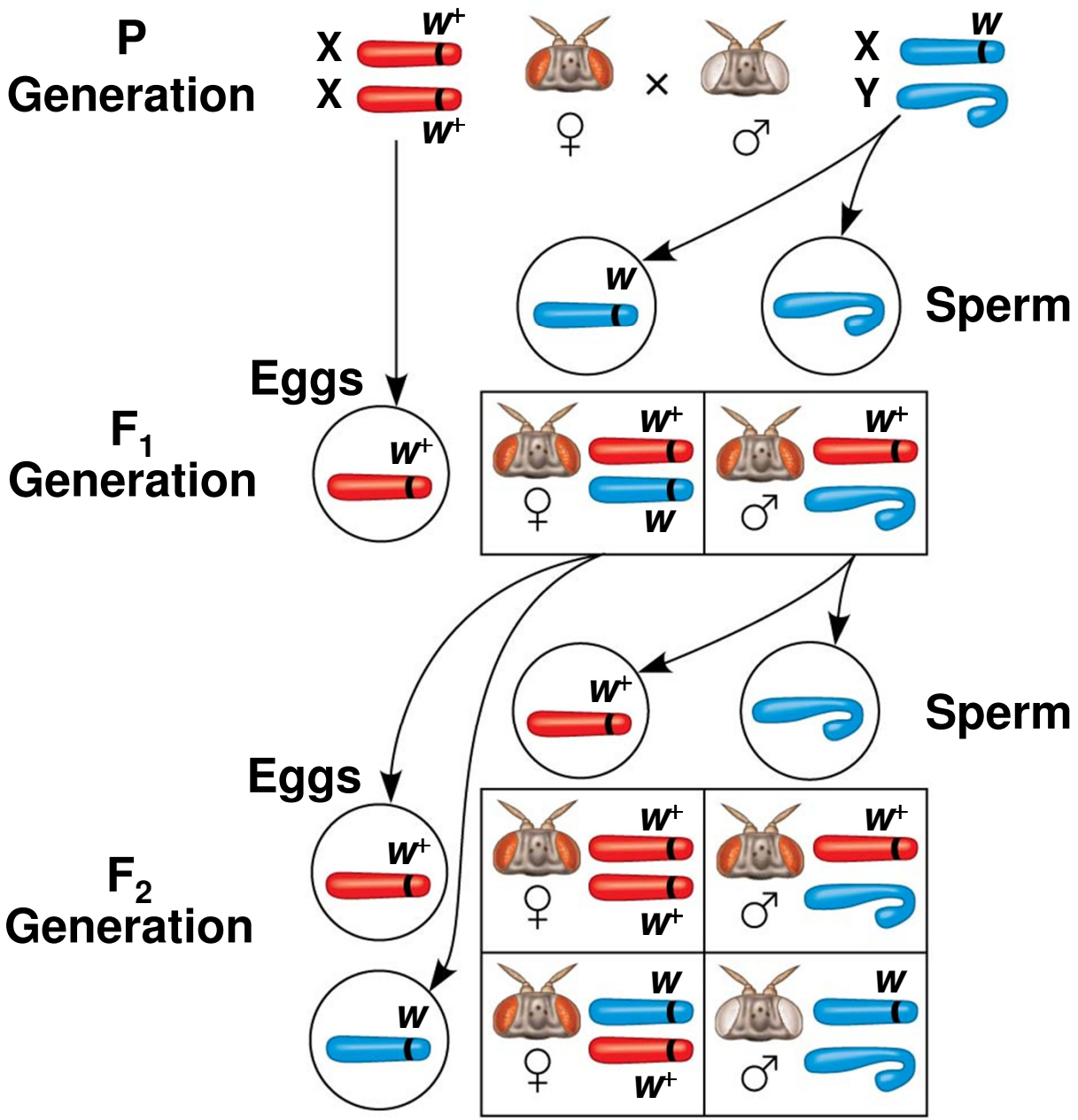

Experiment
P Generation
♀
×
♂
F1 Generation
All offspring had red eyes.
Results
F2 Generation
♀
♀
♂
♂

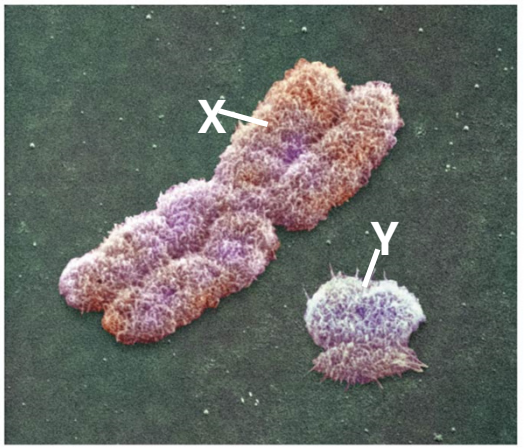
Figure 12.4b

Conclusion



Concept 12.2: Sex-linked genes exhibit unique patterns of inheritance

- In humans and some other animals, there is a chromosomal basis of sex determination
- In humans and other mammals, there are two varieties of sex chromosomes
  - A larger X chromosome
  - And a smaller Y chromosome



- Females are XX, and males are XY
- Each ovum contains an X chromosome, while a sperm may contain either an X or a Y chromosome

- A gene that is located on either sex chromosome is called a **sex-linked gene**
- Genes on the Y chromosome are called Y-linked genes
  - There are few of these
  - Passed from father to all sons
- Genes on the X chromosome are called **X-linked genes**

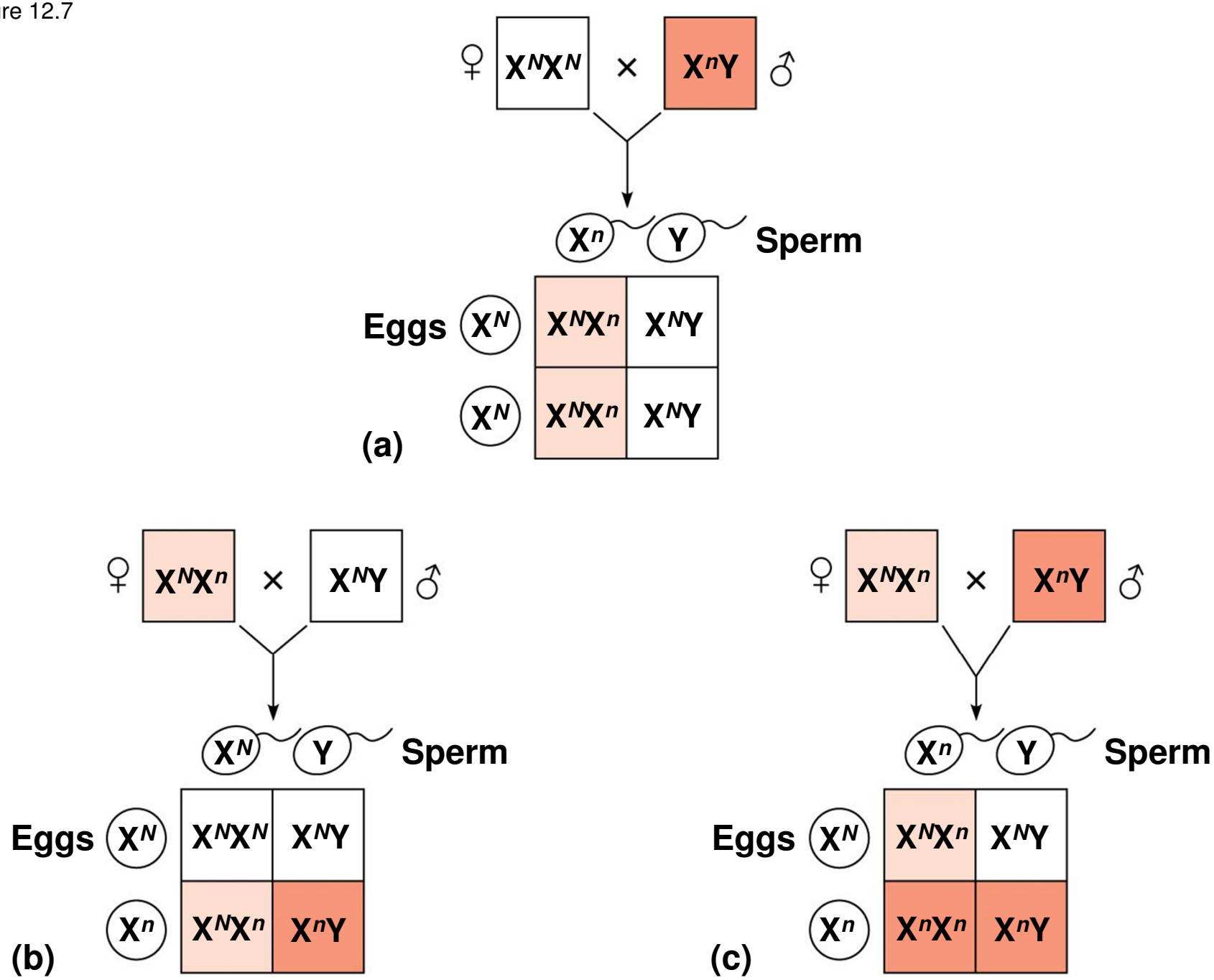
Inheritance of X-Linked Genes

- Y chromosome mainly encodes genes related to sex determination
- X chromosomes have genes for many characters unrelated to sex

- Father's pass X-linked alleles to ALL of their daughters but NONE of their sons!
- Mother's can pass X-linked alleles to both sons and daughters

- For a recessive X-linked trait to be expressed
  - A female needs two copies of the allele (homozygous)
  - A male needs only one copy of the allele (*hemizygous*)
- X-linked recessive disorders are much more common in males than in females
  - Any male receiving the recessive allele from his mother will express the trait
  - But females can inherit the trait from an affected father and a mother who is a carrier

Figure 12.7

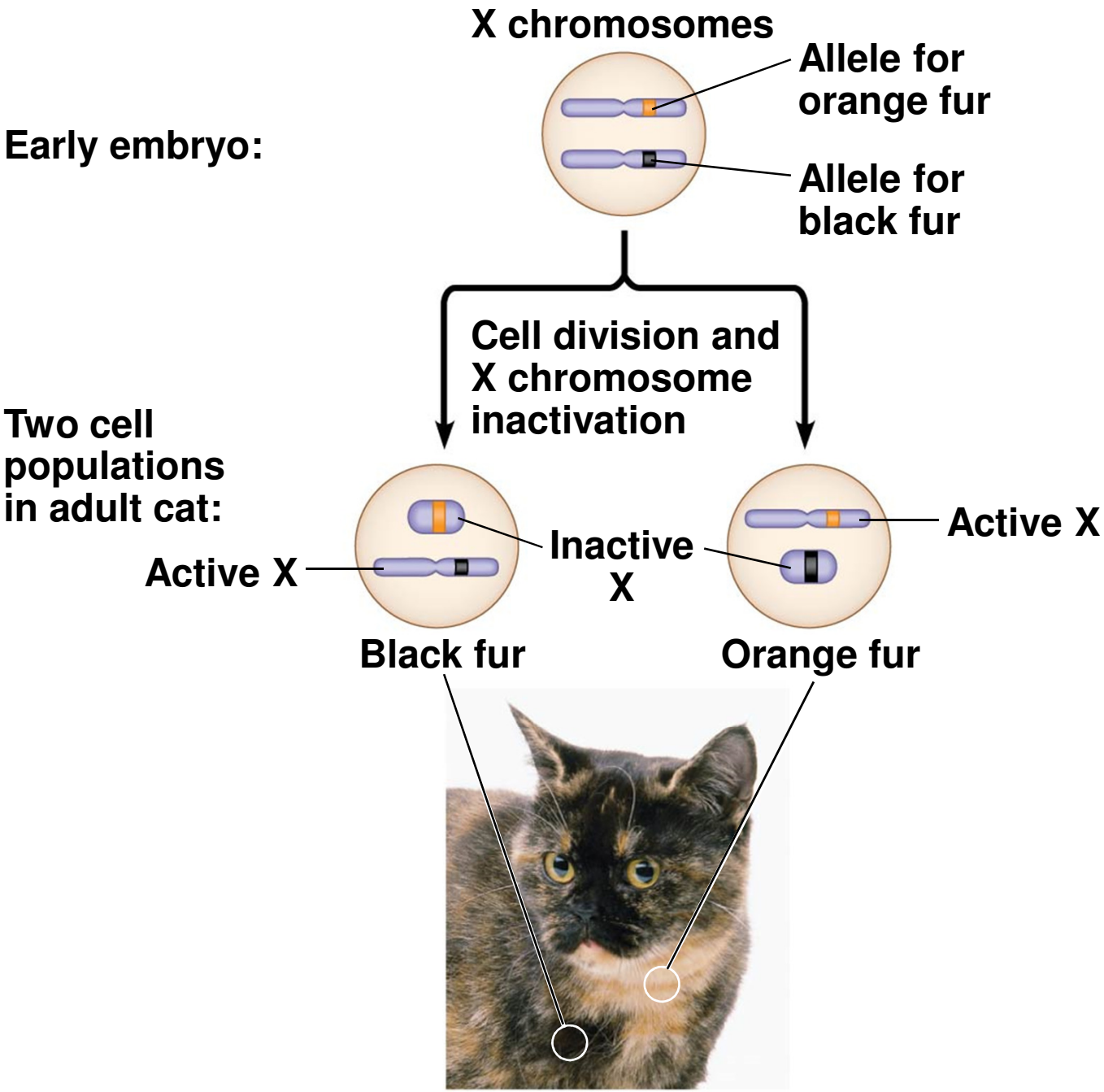

♀ X^NX^N × X^nY ♂
X^n Y Sperm
Eggs X^N X^NX^n X^NY
X^N X^NX^n X^NY
(a)
♀ X^NX^n × X^NY ♂
X^N Y Sperm
Eggs X^N X^NX^N X^NY
X^n X^NX^n X^nY
(b)
♀ X^NX^n × X^nY ♂
X^n Y Sperm
Eggs X^N X^NX^n X^NY
X^n X^nX^n X^nY
(c)

- Some disorders caused by recessive alleles on the X chromosome in humans
  - Color blindness (mostly X-linked)
  - **Duchenne muscular dystrophy**
    - Progressive weakening and loss of muscle tissue
  - **Hemophilia**
    - Absence of blood clotting proteins resulting in excessive bleeding following injury

X Inactivation in Female Mammals

- In mammalian females, one of the two X chromosomes in each cell is randomly inactivated during embryonic development
- The inactive X condenses into a **Barr body**
- If a female is heterozygous for a particular gene located on the X chromosome, she will be a mosaic for that character

Figure 12.8


X chromosomes
Allele for orange fur
Allele for black fur
Early embryo:
Cell division and X chromosome inactivation
Two cell populations in adult cat:
Active X
Inactive X
Active X
Black fur
Orange fur

Concept 12.3: Linked genes tend to be inherited together because they are located near each other on the same chromosome

- Each chromosome has hundreds or thousands of genes (except the Y chromosome)
- Genes located on the same chromosome that tend to be inherited together are called **linked genes**

How Linkage Affects Inheritance

- Morgan did experiments with fruit flies that show how linkage affects inheritance of two characters
  - He crossed flies that differed in traits of body color and wing size
- Morgan found that body color and wing size are usually inherited together in specific combinations
  - He reasoned that since these genes did not assort independently, they were on the same chromosome

Figure 12.UN01

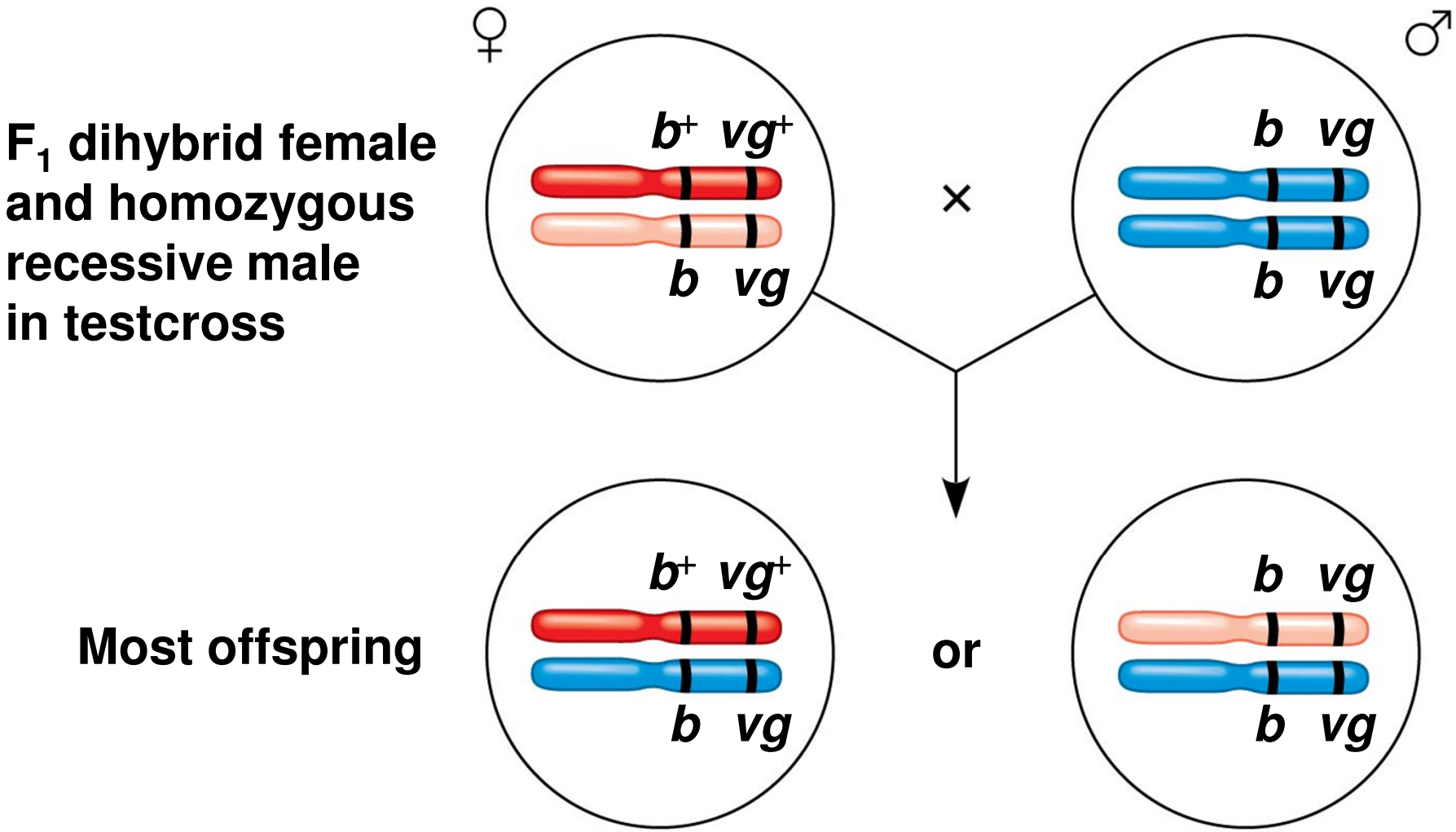


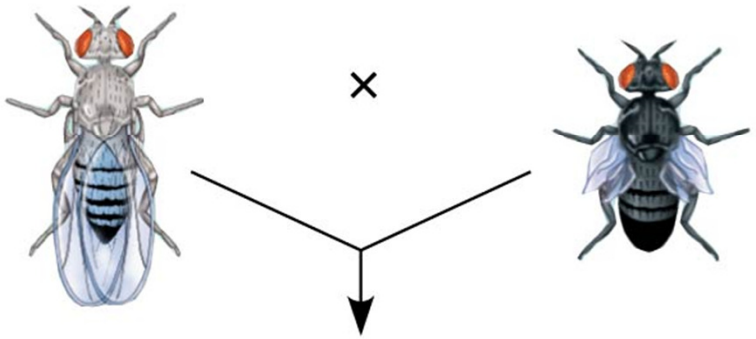
Figure 12.9a

Experiment

P Generation (homozygous)

Wild type (gray body, normal wings)

***b*⁺ *b*⁺ *vg*⁺ *vg*⁺**



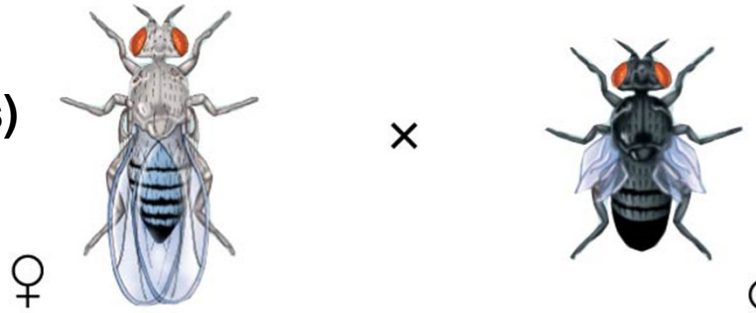
Double mutant (black body, vestigial wings)

b b vg vg

F_1 dihybrid testcross

Wild-type F_1 dihybrid (gray body, normal wings)

b*⁺ *b* *vg*⁺ *vg



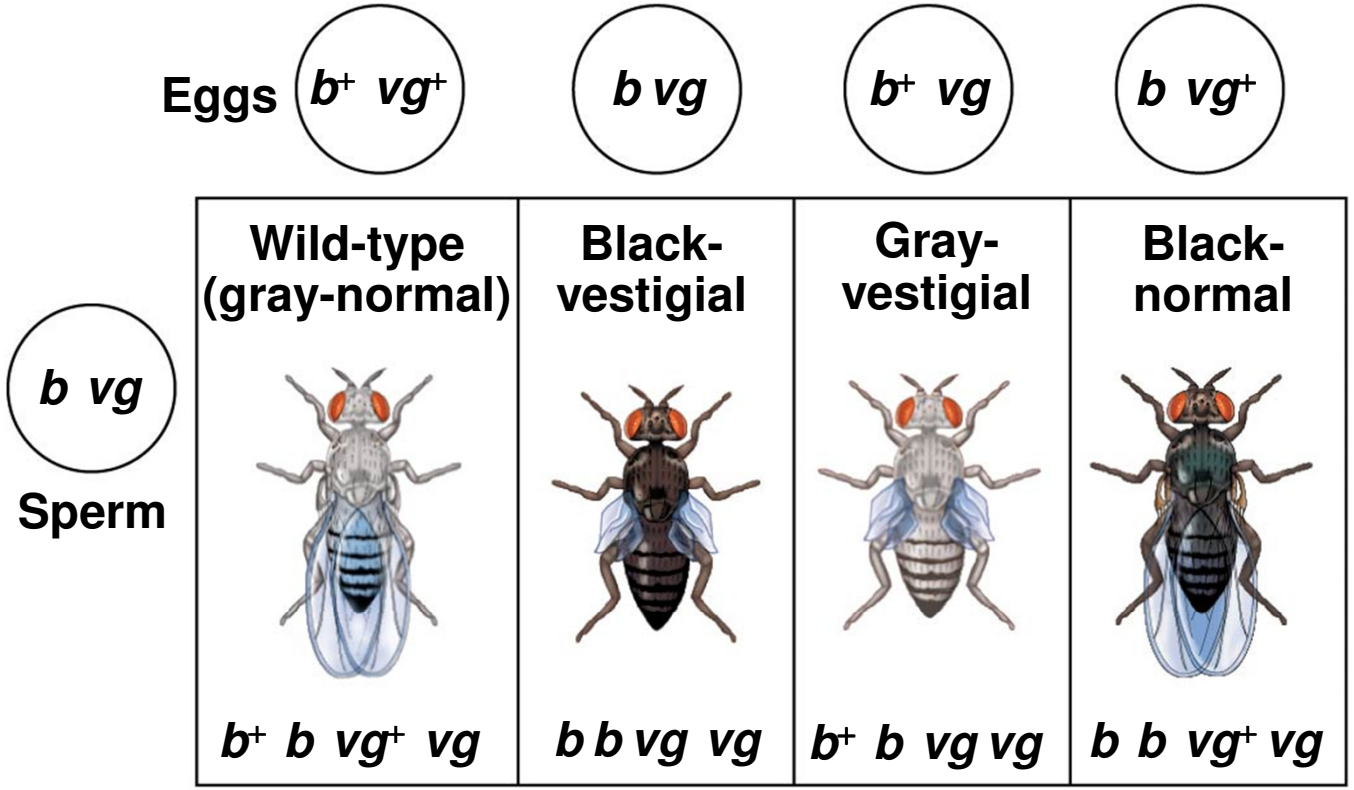
Homozygous recessive (black body, vestigial wings)

b b vg vg

Figure 12.9b

Experiment

Testcross offspring



PREDICTED RATIOS

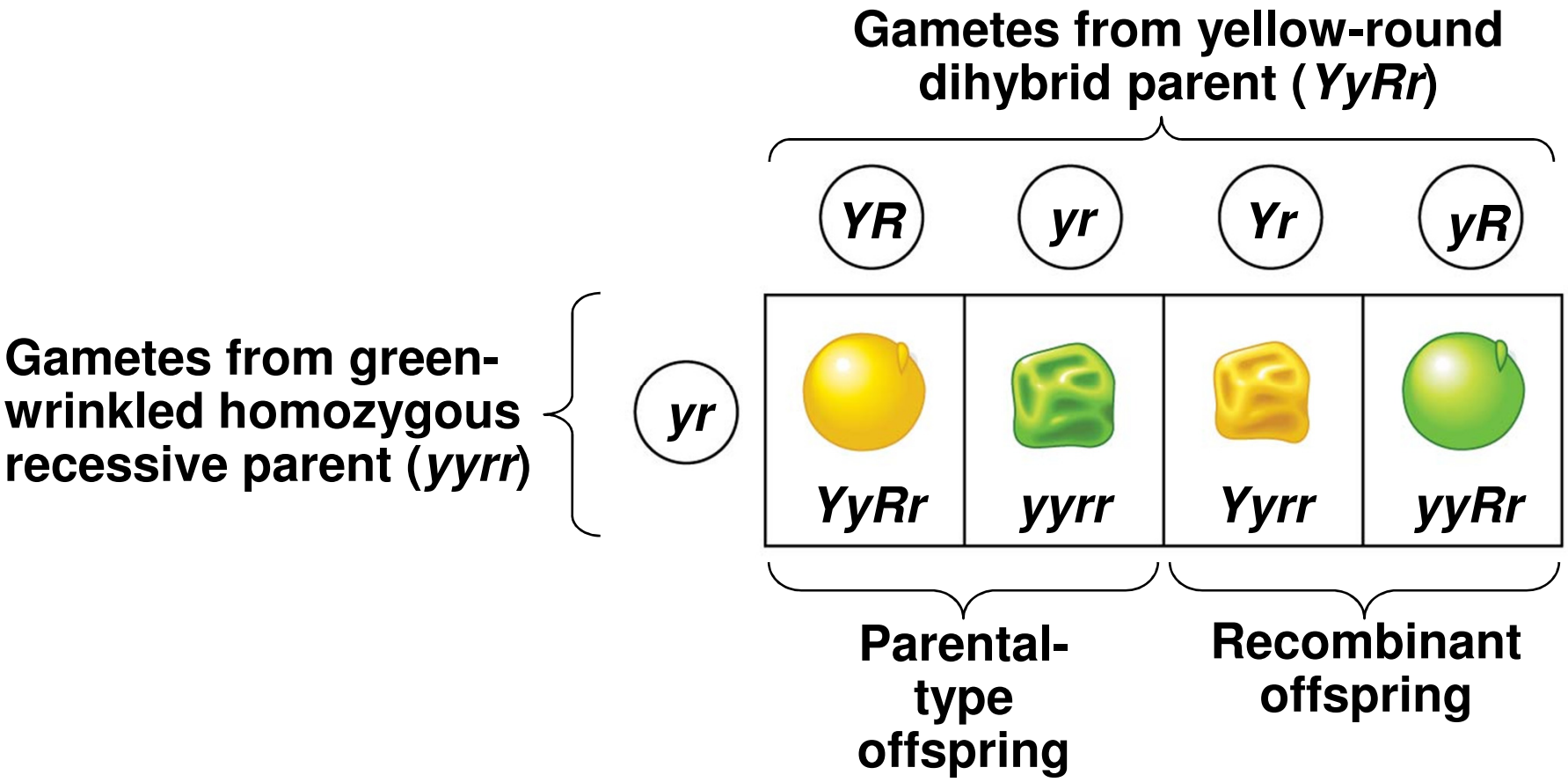
Genes on different chromosomes:	**1**	**:**	**1**	**:**	**1**	**:**	**1**
Genes on same chromosome:	**1**	**:**	**1**	**:**	**0**	**:**	**0**
Results	**965**	**:**	**944**	**:**	**206**	**:**	**185**

- However, nonparental phenotypes were also produced
- Understanding this result involves exploring **genetic recombination**, the production of offspring with combinations of traits differing from either parent

Recombination of Unlinked Genes: Independent Assortment of Chromosomes

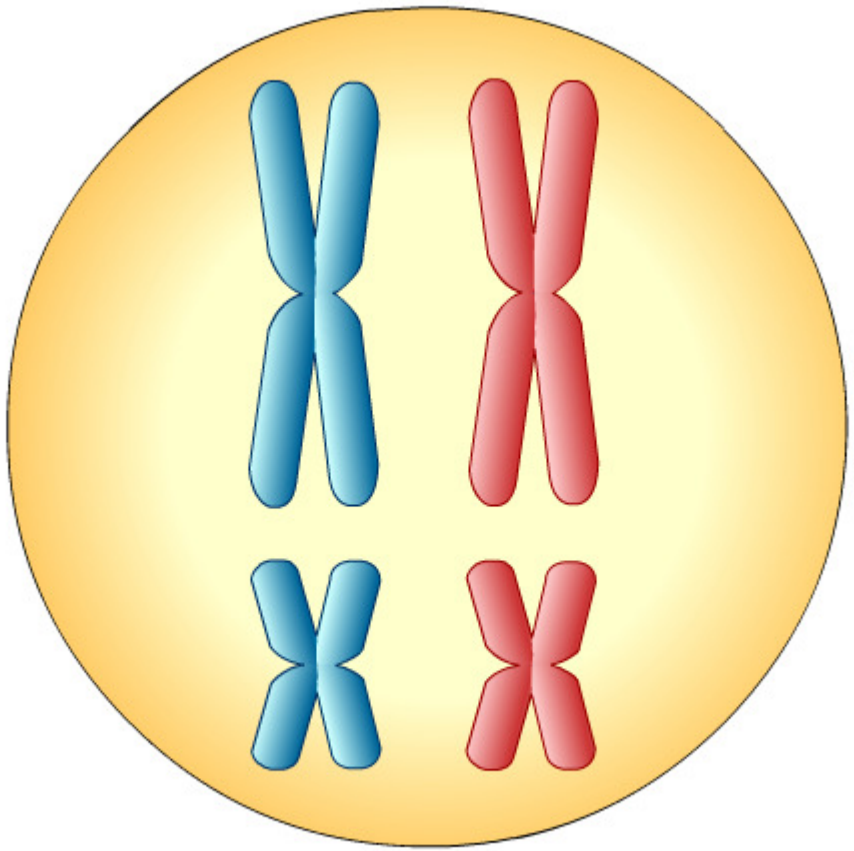
- Mendel observed that combinations of traits in some offspring differ from either parent
- Offspring with a phenotype matching one of the parental phenotypes are called **parental types**
- Offspring with nonparental phenotypes (new combinations of traits) are called **recombinant types**, or **recombinants**
- A 50% frequency of recombination is observed for any two genes on different chromosomes (unlinked)
  - Due to independent assortment during Metaphase I of meiosis

Figure 12.UN02



Recombination of Linked Genes: Crossing Over

- Morgan discovered that even when two genes were on the same chromosome, some recombinant phenotypes were observed
- He proposed that some process must occasionally break the physical connection between genes on the same chromosome
- That mechanism was the **crossing over** between homologous chromosomes
  - End portions of two nonsister chromatids trade places
  - Accounts for recombination of linked genes



Animation: Crossing Over
Right click slide / Select play

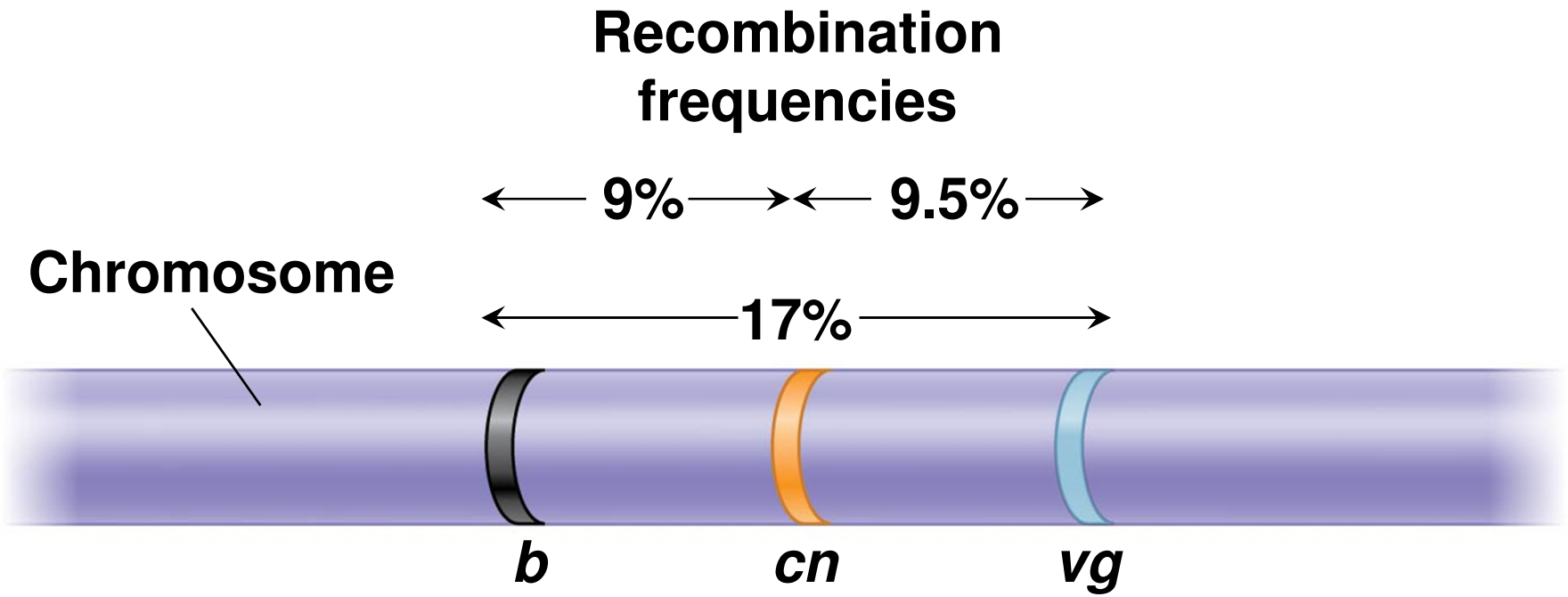
New Combinations of Alleles: Variation for Normal Selection

- Recombinant chromosomes bring alleles together in new combinations in gametes
- Random fertilization increases even further the number of variant combinations that can be produced
- This abundance of genetic variation is the raw material upon which natural selection works

Mapping the Distance Between Genes Using Recombination Data: *Scientific Inquiry*

- Alfred Sturtevant, one of Morgan's students, constructed a **genetic map**
  - Ordered list of the genetic loci along a particular chromosome
- Sturtevant hypothesized that the recombination frequency depends on the distance between genes on a chromosome
  - *The farther apart two genes are, the higher the probability that a crossover will occur between them and therefore the higher the recombination frequency*

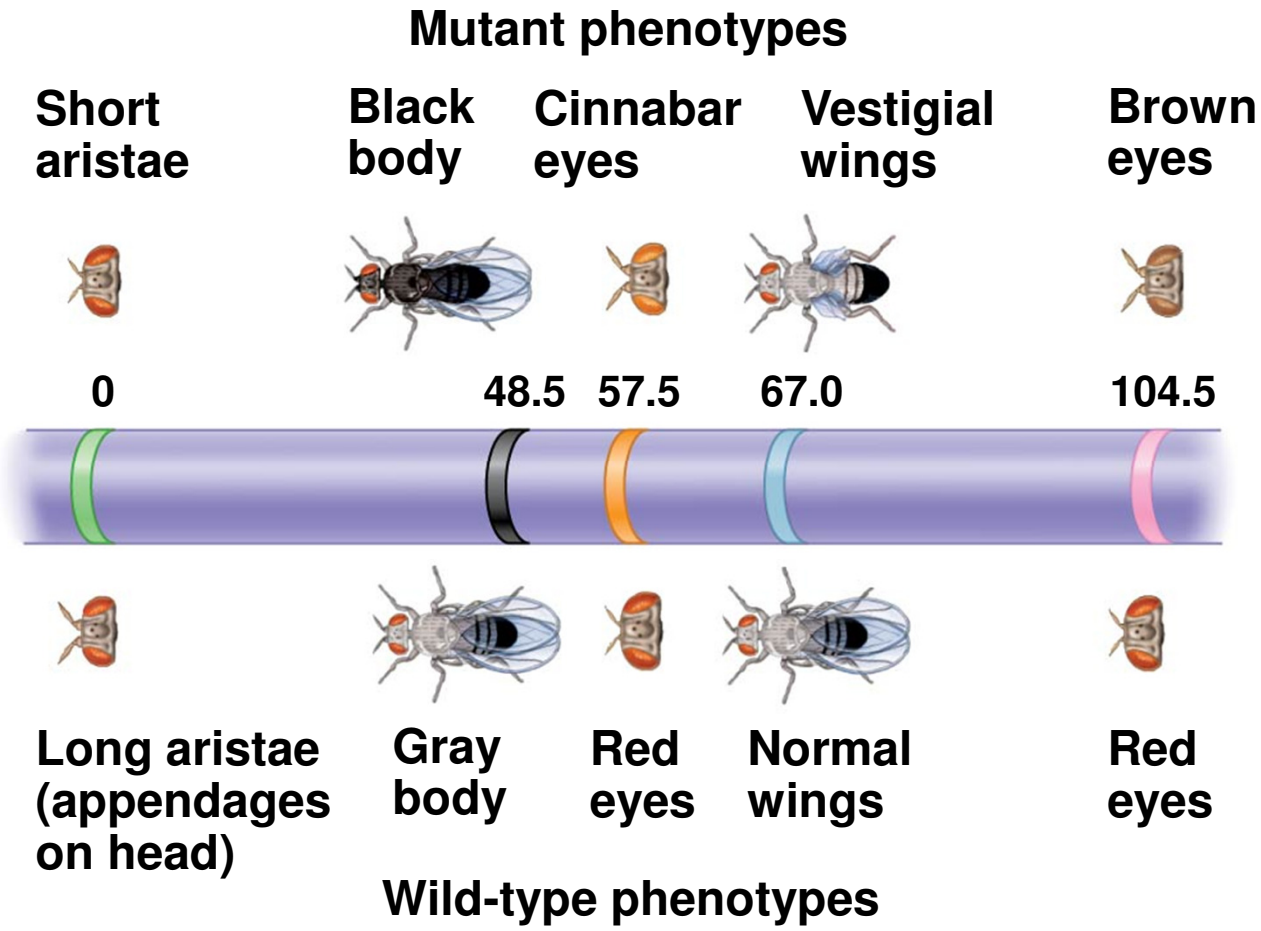
- A **linkage map** is a genetic map of a chromosome based on recombination frequencies
- Distances between genes can be expressed as **map units**
  - One map unit represents a 1% recombination frequency



- Genes that are far apart on the same chromosome can have a recombination frequency near 50%
  - Such genes are physically linked by being on the same chromosome
  - But genetically unlinked and sort independently
  - Thus behave as if found on different chromosomes!

- Sturtevant used recombination frequencies to make linkage maps of fruit fly genes
  - Each chromosome has a linear array of specific genes and each gene has its own locus
- A linkage map portrays the order of genes along a chromosome
  - It does not accurately portray the precise location of those genes
- Using methods like chromosomal banding, geneticists can develop cytogenetic maps of chromosomes
  - **Cytogenetic maps** indicate the positions of genes with respect to chromosomal features

Figure 12.12

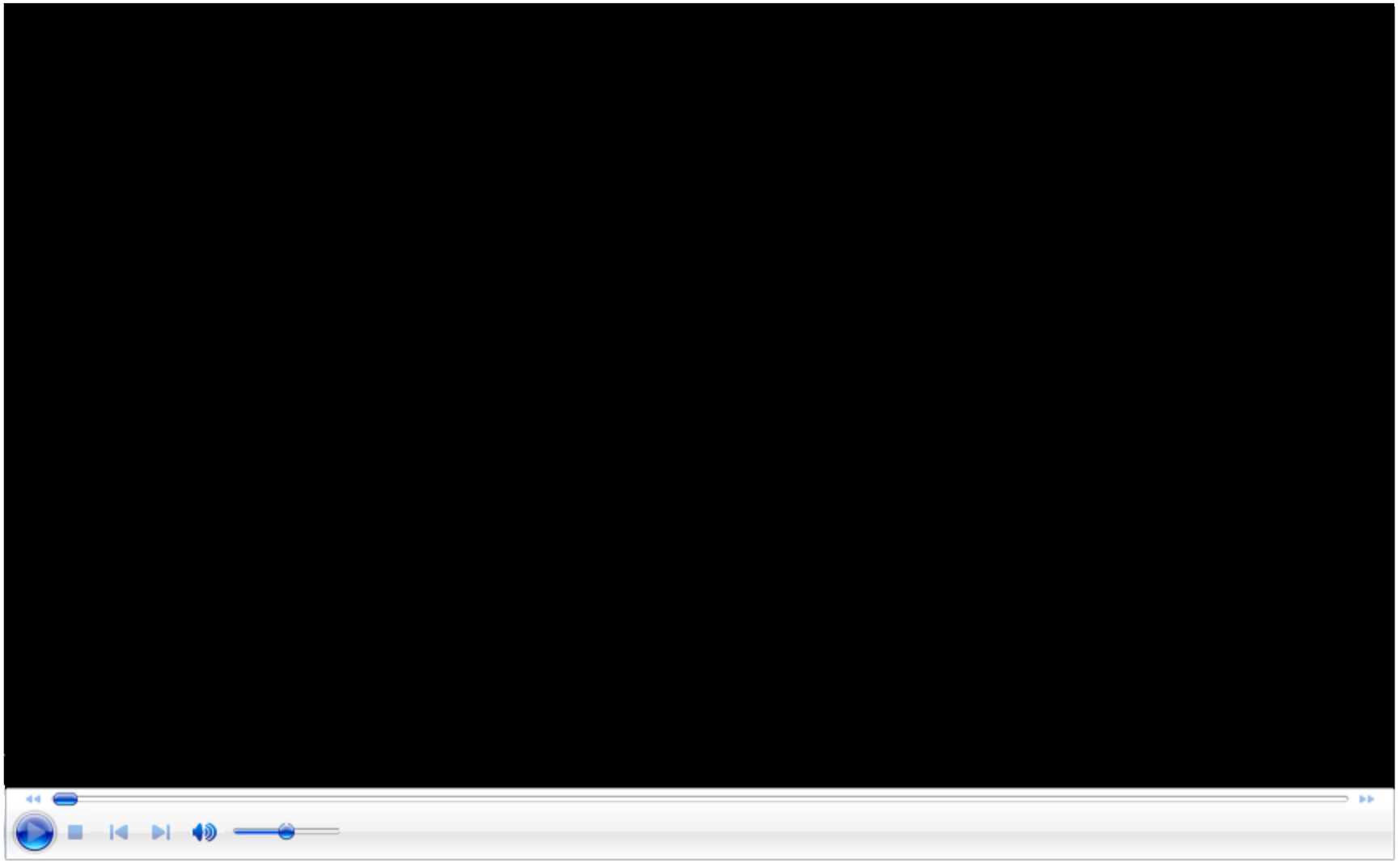

Mutant phenotypes
Short aristae
Black body
Cinnabar eyes
Vestigial wings
Brown eyes
0
48.5
57.5
67.0
104.5
Long aristae (appendages on head)
Gray body
Red eyes
Normal wings
Red eyes
Wild-type phenotypes

Concept 12.4: Alterations of chromosome number or structure cause some genetic disorders

- Large-scale chromosomal alterations in humans and other mammals often lead to spontaneous abortions (miscarriages) or cause a variety of developmental disorders
- Plants tolerate such genetic changes better than animals do

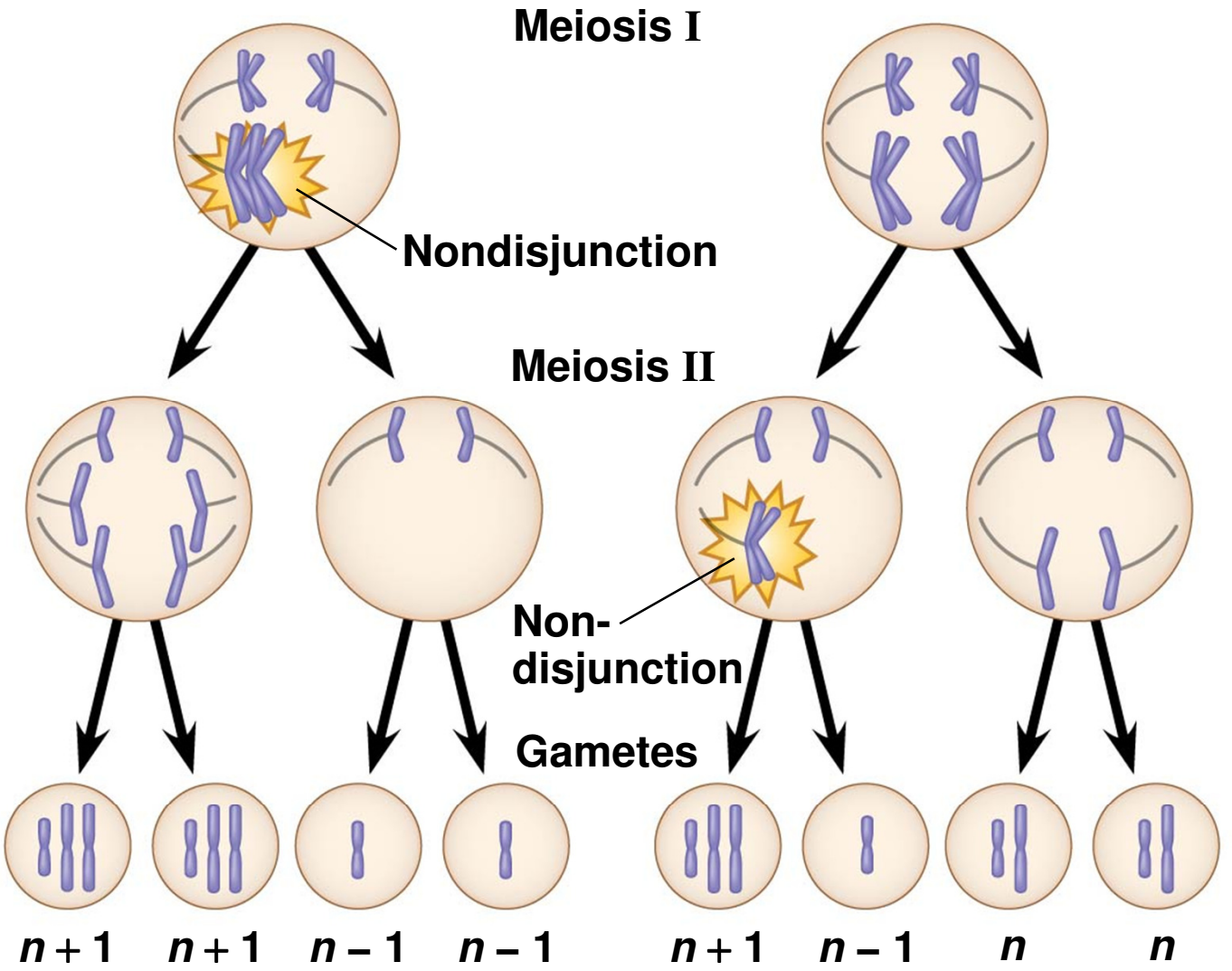
Abnormal Chromosome Number

- In **nondisjunction**, pairs of homologous chromosomes do not separate normally during anaphase of meiosis
- As a result, one gamete receives two of the same type of chromosome, and another gamete receives no copy



Video: Nondisjunction

Figure 12.13-3



(a) Nondisjunction of homologous chromosomes in meiosis I

(b) Nondisjunction of sister chromatids in meiosis II

- **Aneuploidy** results from the fertilization of gametes in which nondisjunction occurred
- Offspring with this condition have an abnormal number of a particular chromosome
- A **monosomic** zygote has only one copy of a particular chromosome
- A **trisomic** zygote has three copies of a particular chromosome
  - Ex: Down syndrome (Trisomy 21)

- **Polyploidy** is a condition in which an organism has more than two complete sets of chromosomes
  - Triploidy (3*n*) is three sets of chromosomes
  - Tetraploidy (4*n*) is four sets of chromosomes
- Polyploidy is common in plants, but not animals
  - Bananas are triploid
  - Wheat is hexaploid (6n)
  - Strawberries are octoploid (8n)
- Polyploids are more normal in appearance than aneuploids

Alterations of Chromosome Structure

- Errors in meiosis or damaging agents like radiation can cause breakage of a chromosome
- This can lead to four types of changes in chromosome structure
  - **Deletion** removes a chromosomal segment
    - Missing certain genes
  - **Duplication** repeats a segment
  - **Inversion** reverses orientation of a segment within a chromosome
  - **Translocation** moves a segment from one chromosome to another

Figure 12.14a

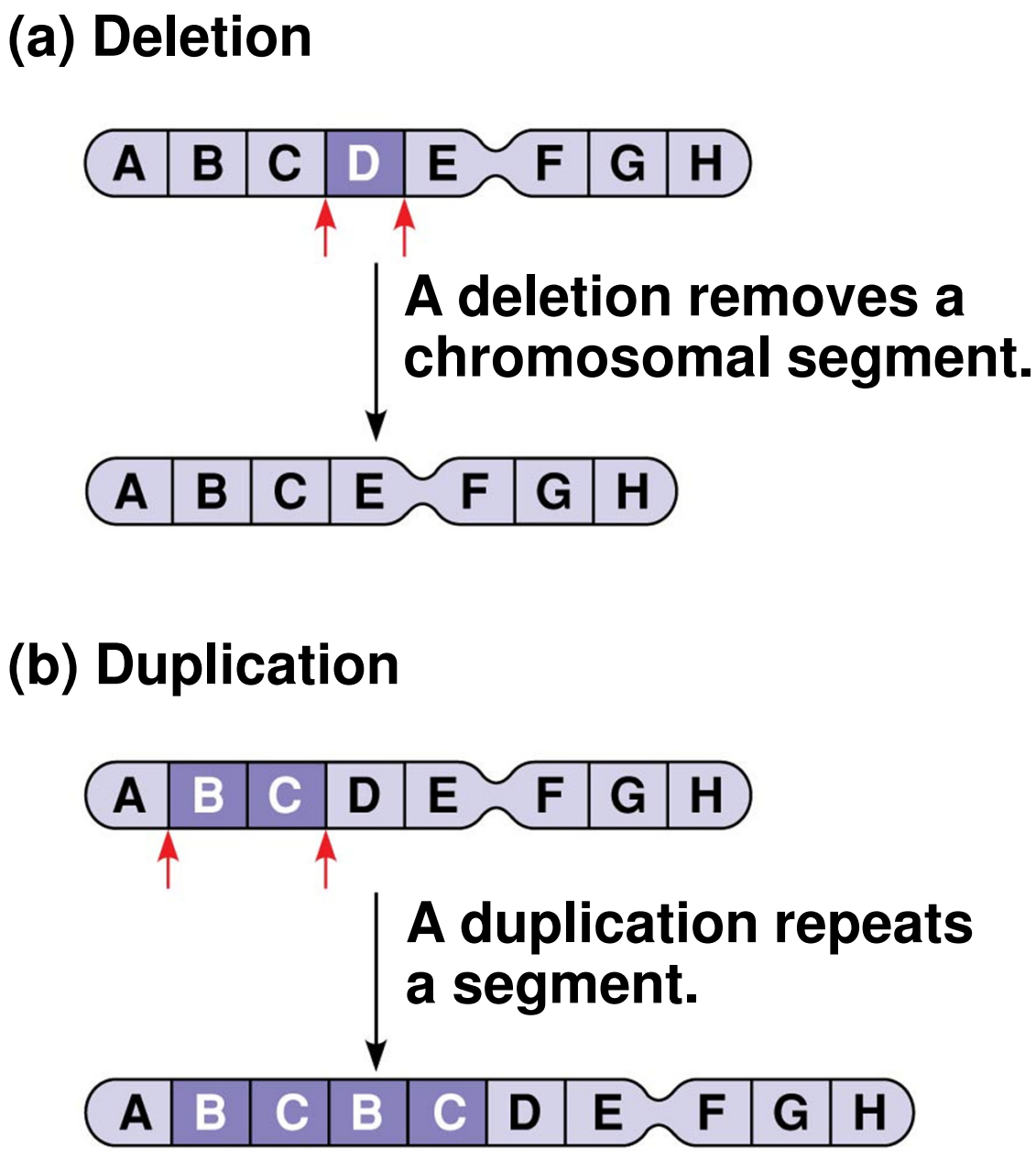
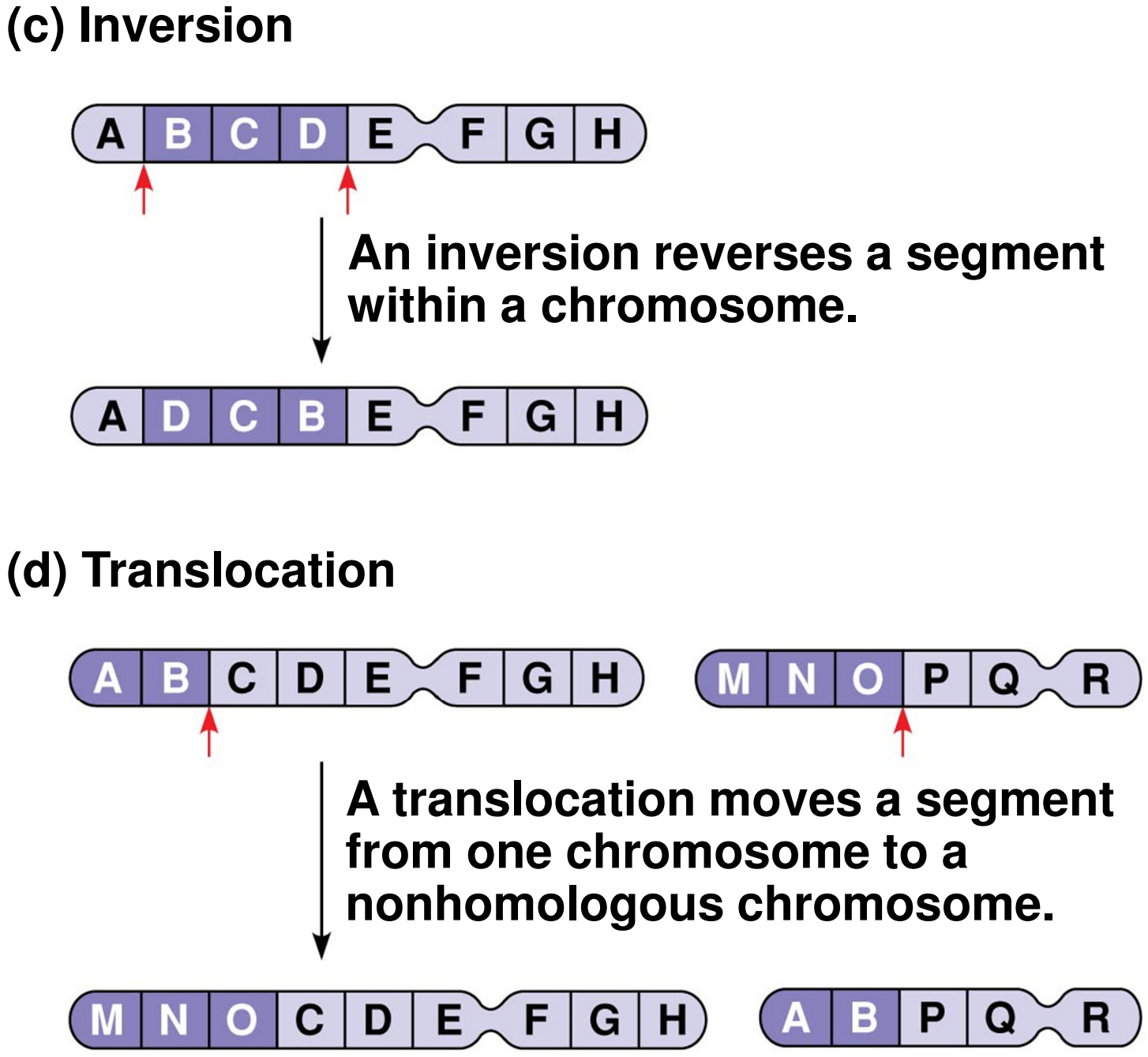


Figure 12.14b



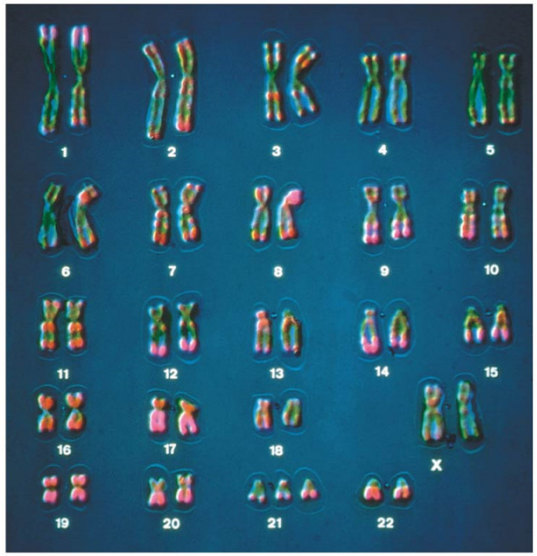
- Deletions and duplications are especially likely to occur during meiosis
  - Unequal exchange in crossing over
- A diploid embryo that is homozygous for a large deletion is likely missing a number of essential genes
  - Generally lethal
- Duplications and translocations also tend to be harmful
- In inversions, the balance of genes is normal but phenotype may be influenced if the expression of genes is altered

Human Disorders Due to Chromosomal Alterations

- Alterations of chromosome number and structure are associated with some serious disorders
- Some types of aneuploidy upset the genetic balance less than others, resulting in individuals surviving to birth and beyond
- These surviving individuals have a set of symptoms, or syndrome, characteristic of the type of aneuploidy

Down Syndrome (Trisomy 21)

- **Down syndrome** is an aneuploid condition that results from three copies of chromosome 21
- It affects about one out of every 700 children born in the United States
- The frequency of Down syndrome increases with the age of the mother



Aneuploidy of Sex Chromosomes

- Nondisjunction of sex chromosomes produces a variety of aneuploid conditions
  - Tend to be less severe than autosomal aneuploids
  - Due to Y chromosome carrying few genes and X inactivation
- Klinefelter syndrome is the result of an extra chromosome in a male, producing XXY individuals
- Females with trisomy X (XXX) have no unusual physical features except being slightly taller than average
- Monosomy X, called Turner syndrome, produces X0 females, who are sterile
  - It is the only known viable monosomy in humans

Disorders Caused by Structurally Altered Chromosomes

- The syndrome *cri du chat* (“cry of the cat”) results from a specific deletion in chromosome 5
  - A child born with this syndrome is mentally retarded and has a catlike cry
  - Individuals usually die in infancy or early childhood
- Certain cancers, including *chronic myelogenous leukemia* (CML), are caused by translocations of chromosomes